Implantable Piezoelectric Generators

Jessica Snyder[1], Beth Lewandowski[2]

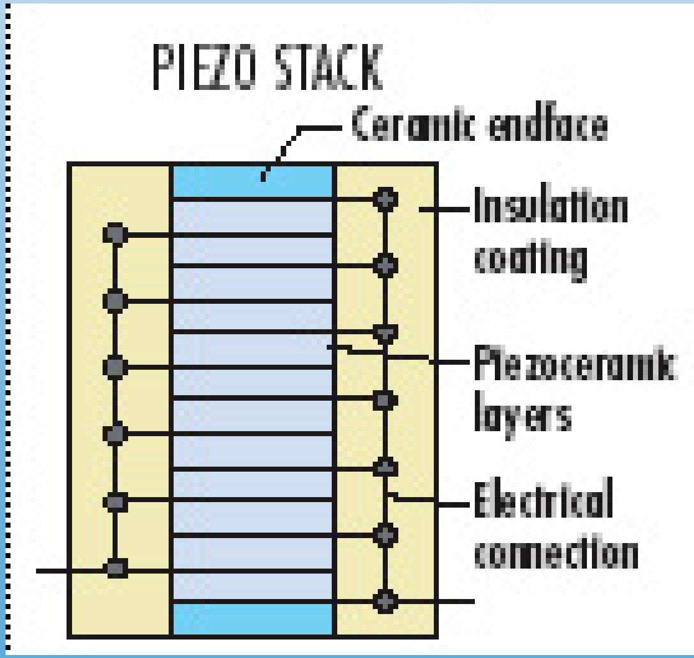
1) Research Associate University of Kansas Lawrence, KS 2) Principal Investigator, Glenn Research Center Cleveland, OH

Project Background

- Piezoelectric generators are currently being studied in a variety of energy harvesting situations.
- The goal of this project is to power implanted electronic medical devices with implanted piezoelectric generators, augmenting or replacing the external power supplies or implanted batteries currently used as power sources.
- Preliminary animal experiments have shown that this may be a viable method of powering internal electrical devices[2].

Intro to Piezoelectrics

- Produce a voltage when stressed mechanically
- Mechanically deflect when exposed to a voltage
- Stacked piezoelectrics are composed of layers of capacitive material connected electrically in parallel and mechanically in series



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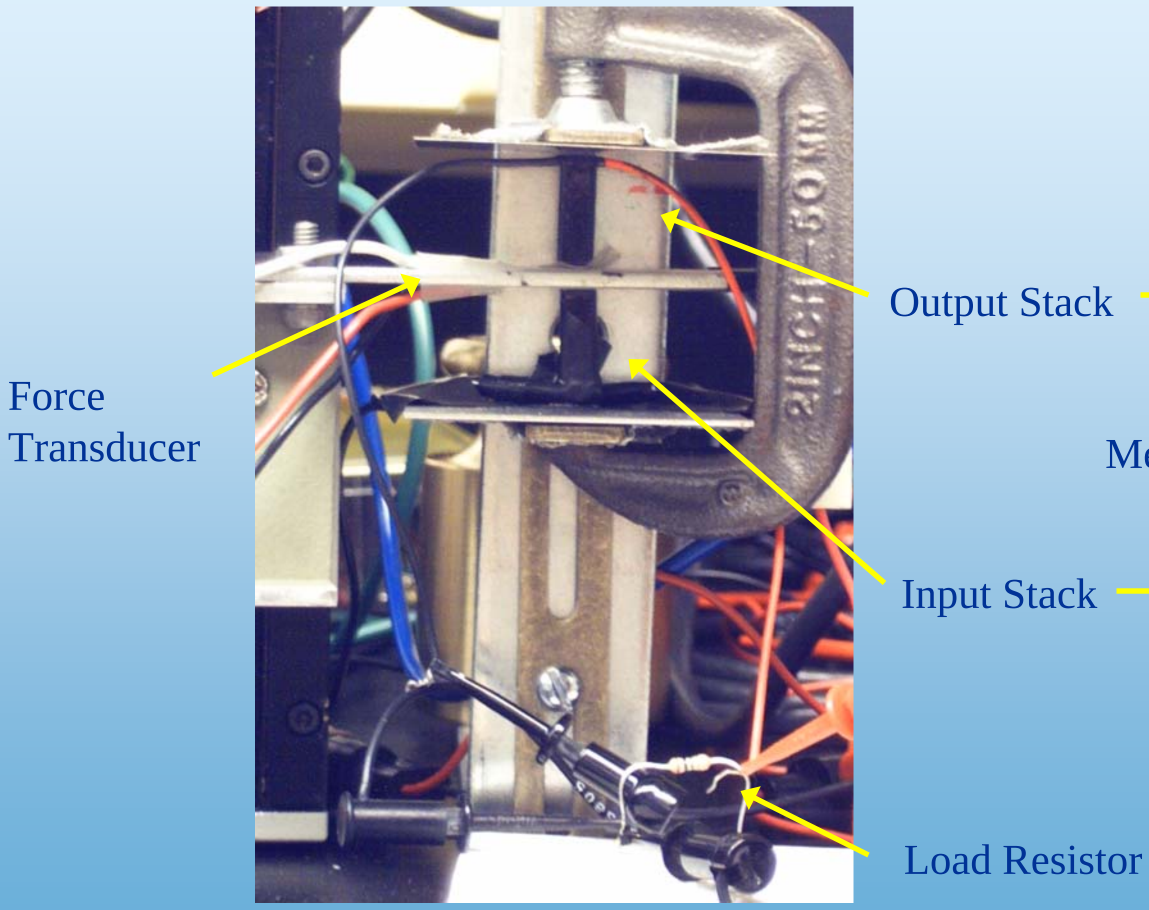
Problem Definition

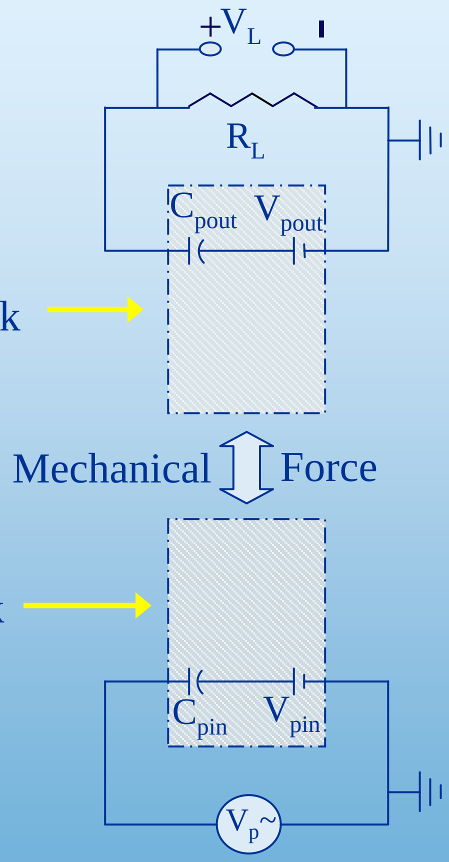
- Goal is to maximize power output of stack generator
- Power output is greatest when impedance of stack is lowest
- Impedance varies with frequency
- Experimentally determine resonance frequencies
- Looking for resonance below 50 Hz, higher frequencies not within range of application

Approach

- Use two stacks, one to actuate one for generation
- Apply AC voltage to actuator
- Measure output peak-to-peak voltage across load resistor in series with generator.
- Record over a frequency range 1Hz to 7KHz
- Use oscilloscope and Flukeview® software to record and save waveforms

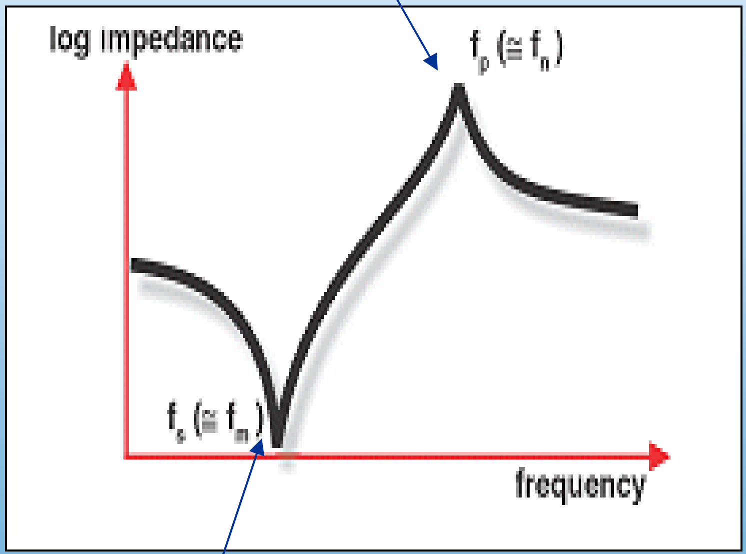
Experimental Set-up





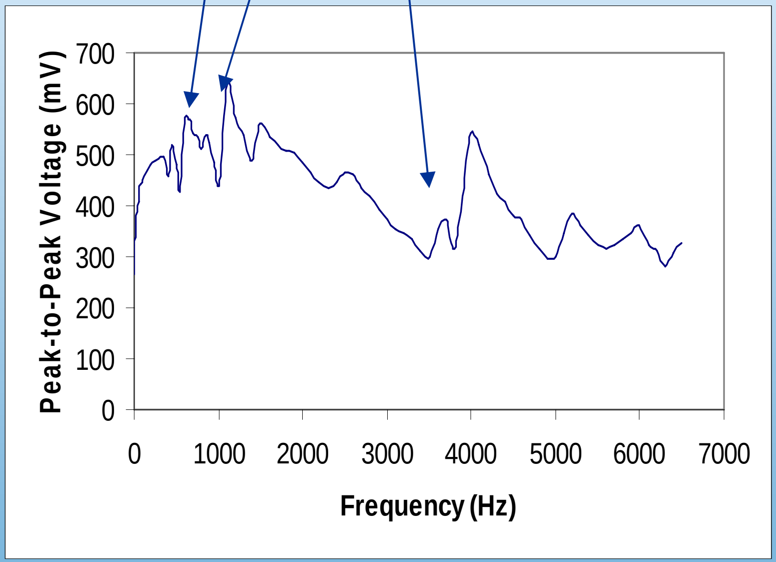
Initial Results

Anti-Resonance



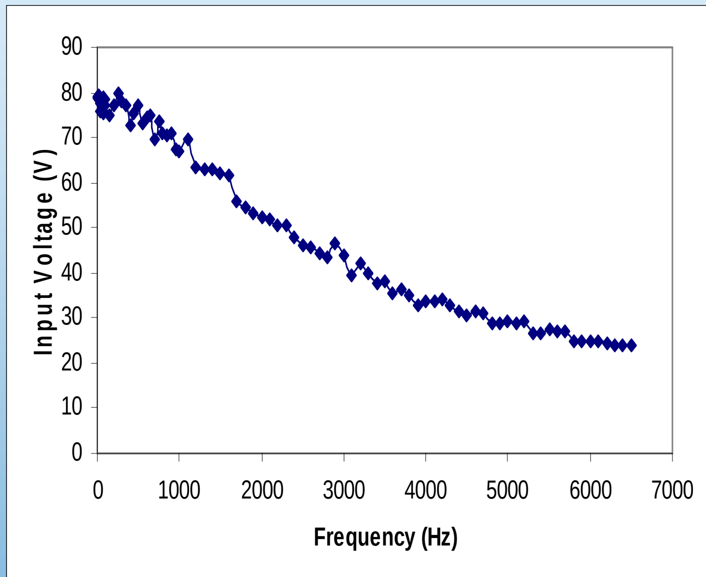
Resonance

Possible Resonances

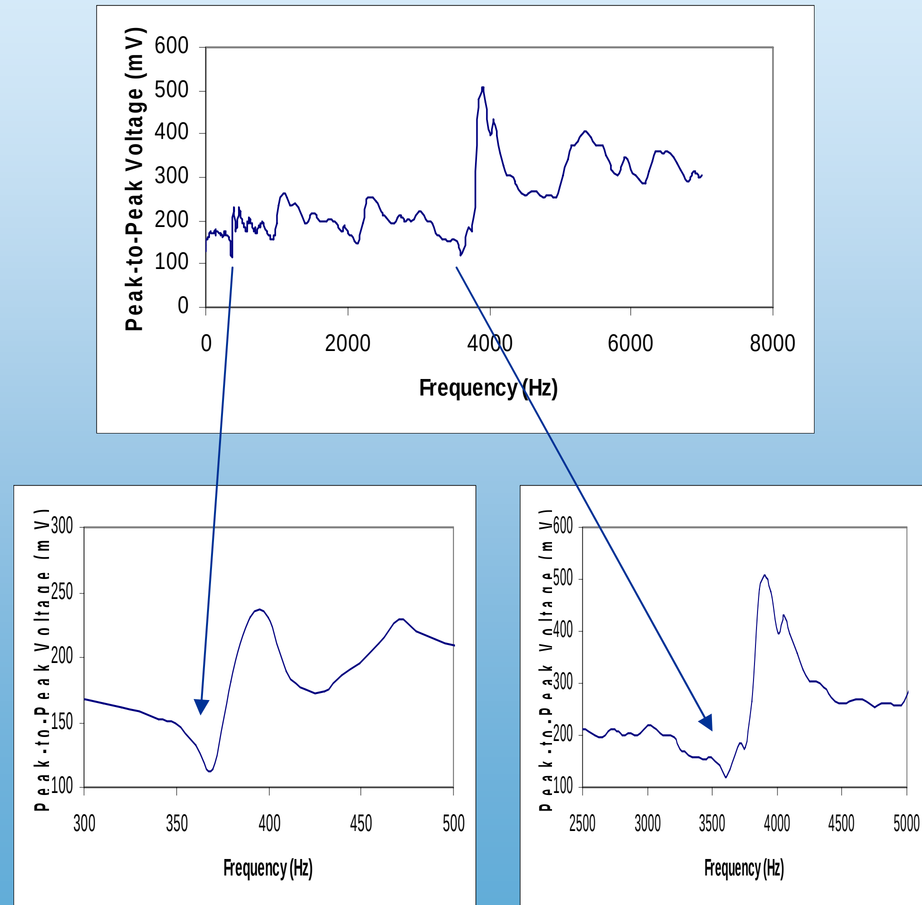


Input Voltage

- Decreasing with increasing frequency



- Manually adjusted input to be constant



Analytical Resonance

- Stack resonances calculable from physical characteristics
- Listed resonance at 74kHz
- Tested stacks with a low field impedance analyzer. No resonance peaks detected under 7kHz
- Without force transducer, not able to determine impedance

Theoretical Approach

Longitudinal: $f_n = n\frac{v}{2L}$

Flexural: $f_n \approx (2n+1)^2 \frac{\pi v d}{16\sqrt{3}\cdot L^2}$

Combined: $\frac{f_{n,long}}{f_{m,flex}} = \frac{8\sqrt{3}\cdot nL}{\pi d(2m+1)^2}$

Theoretical Comparison

	m=1		m=2	
f_long/f_flex	n		n	
f_3/f_2	1.257	f_3=1st long; f_2=1st flex	3.491	
f_3/f_4	0.338		0.940	f_3=1st long; f_4=2nd flex
f_4/f_2	2.105	f_4=2nd long; f_2=1st flex;	5.848	
f_4/f_3	0.949	f_4=1st long; f_3=1st flex	2.637	

Theoretical Comparison

	Speed of Sound (*v*) m/s	
Frequency (Hz)	**Longitudinal**	**Flexural**
370	13.32	23.50
950	16.92	25.09
2151	25.81	25.09
3600	32.40	25.41
Average	22.11	23.93
Percent error	39.06%	7.07%

Conclusions

- No resonances detected within the design range (<50Hz) of the implantable piezoelectric generator
- Discrepancies between these results and those of the impedance analyzer are most likely due to the difference in the applied electric field. A high electric filed was used in these tests as compared to the low filed used by the impedance analyzer.
- Speed of sound is not 24 m/s through piezoelectric stacks but obtaining the same value for all for frequencies is notable and should be further investigated

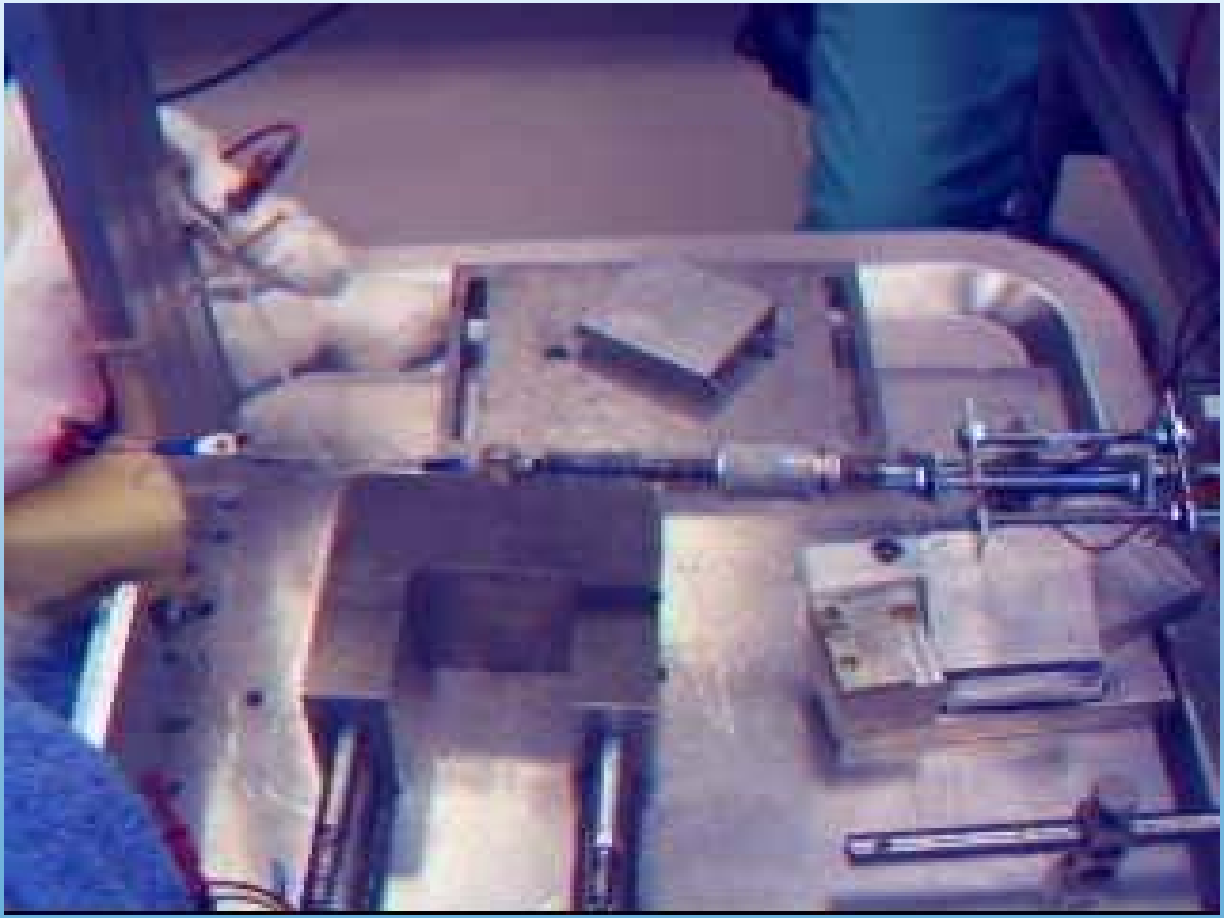
Future Work

- Measure power output vs. frequency
- Advances is piezoelectrics may produce stacks with lower resonance frequencies
- It may be possible to develop a system or device which can convert a lower frequency to a higher one

Rabbit Experiment

- Goal is to show that less energy is used to stimulate the muscle than the muscle is able to output through the generator
- Rabbit muscle is stimulated via nerve cuff
- Force of twitch is transmitted to generator
- Energy is collected and stored in capacitor

Rabbit Experiment



Acknowledgements

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References

1. 1. APC International, Ltd. *Determining Resonance Frequency.* www.americanpiezo.com/piezo_theory/resonance_frequency.html

2. Lewandowski, B.E., K.L. Kilgore, and K.J. Gustafson. *Design Considerations for an Implantable, Muscle Powered Piezoelectric System for Generating Electrical Power*. Annals of Biomedical Engineering, 2007. 35(1): p.631-641.